NHDOT Research Project 26962P
Reducing Cracks in New Bridge Curbs

Review of Cracking in Existing Bridge Curbs

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Submitted by:

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Executive Summary

As part of the New Hampshire Department of Transportation research study 26962P, a review of cracking extent and intensity in concrete bridge curbs throughout New Hampshire was conducted between May – August 2017. Curb cracking in 13 single-span bridges was documented. A system was developed to classify each crack by its width and length. The goal of visiting existing bridges was to infer from them what may be the cause of early-age cracking experienced by newly constructed bridge curbs. One finding was that larger bridge spans experienced more cracking per foot as well as cracks of longer lengths than bridges with shorter spans. The data also suggests that the highest rate of new crack formation occurs in the early years of the curbs life. Guardrail posts did not show to have influence in causing higher amount of cracks than other sections of the curb. Also, the cracking does not appear to have bias towards middle or end sections of the span.

Introduction

Over the summer of 2017, 13 bridge curbs that had been reconstructed since 2010 were visited. The purpose of the visits was to document the intensity and frequency of cracking along the bridge curbs in order to gain an insight into what conditions may lead to early-age cracking. The goal was to find existing bridge curbs with minimal cracking and try to mimic their construction in future test curbs. The bridges in this study ranged from 12 feet to 24 feet. All of the bridges were single span bridges and all but one was constructed by NHDOT's Bureau of Bridge Maintenance.

Bridges Visited

In an attempt to find causes of early-age cracking without looking at every bridge in the NHDOT inventory it was decided that ten to twelve bridges would be visited. Since this study is looking at what can be done to current practices to mitigate cracking, only curbs reconstructed since 2010 were considered for site visits. Bridges in various parts of the state were looked at in order to identify any variations due to climate or crew procedures. Different span lengths were also investigated. Ultimately, 13 bridges were visited. One bridge was a precast curb placed in the winter of 2017 (Sunapee, 112/074) and one was constructed outside of the Bureau of Bridge Maintenance (Berlin, 194/097). A list of bridges is shown in Table 1.

Table 1: Bridges visited for the review

Town	Bridge Number	Year Constructed	Span Length (ft)
Chesterfield	080/120	2010	41
Epsom	160/111	2010	21
Canaan	178/141	2011	47
Jefferson (Israel River)	087/096	2011	84
Wakefield	230/057	2012	52
Chichester	130/100	2013	15
Bow	052/140	2014	31
Pittsburg	070/032	2014	94
New Boston	045/131	2015	17
Albany	080/148	2015	73
Jefferson (Cherry Mill Brook)	089/090	2015	28
Berlin	194/097	2016	12
Sunapee	112/074	2017	20

Procedure

In order to reduce errors and improve safety when collecting data, a two-part procedure was developed. Part one included the field visit to the site to take photographs. The second part involved review of photos on a computer to catalog the cracks. This reduced the time spent on bridges with traffic.

Field Visits

Upon arriving to the site, broad observations were made and documented using video recording. The recording included information on traffic, bridge surroundings, superstructure material, or any other noteworthy observations. Following initial observations, a tape measure was pulled from one end of the curb to the other (Figure 1). Locations of guardrail post centers from the end of the curb were recorded. Total curb length was also noted.

Figure 1: Tape measure on bridge curb

Photos were taken at each crack along the curb with the tape measure in view as well as a crack comparator (Figure 2). When cracks were hairline in width the crack comparator was excluded from the photo. In order to capture the details of some cracks multiple photos were taken.

The remaining curb was inspected upon completion of the first. The same procedure was also used. One important note is that the tape measure was pulled from the same end of the bridge as the first. This method provides consistency on repeated visits and also acts as a check when viewing photos later as the tape measure will appear upside down for one side of the bridge. This helps prevent crack images on one side being confused with the other side. After the data was recorded any final comments and observations were made.

Figure 2: Crack comparator used to size cracks

Data Analysis

The photos and videos were downloaded to a computer after site visits. Photos were viewed and the cracks were catalogued in a spreadsheet. Curbs were identified by the cardinal direction that most resembled their location on the bridge (north, south, east, or west). Cracks were identified by their location from the end of the curb which was identifiable in photos due to the tape measure.

Each crack had two further classifications: an intensity and length index. The crack intensity was a relative measure of the crack width. A system from one to three was used to classify the crack. A one indicated a small crack and a three indicated a large crack. The crack index also followed a similar system with a 1 being short crack and 3 being a long crack. The actual values used to identify the intensity and length index are shown in Figure 3. In addition to crack length and intensity, the bridge span, curb length, guardrail post locations, and superstructure material was also reported.

Intensity and Length Classification

Intensity

1	Crack width of 0.004” or less
2	Crack width between 0.004” and 0.016”
3	Crack width of 0.016” or greater

Length Index

1	Partial cracking on one or two faces of curb
2	Full or nearly full cracking along one face with or without partial cracking along another face
3	Full cracking along at least two faces or a crack extending from the guardrail post to bottom of the front face of the curb

Figure 3: Categories for crack width and length index

Results and Discussion

The following graphs and paragraphs highlight some of the key trends discovered during the existing site visits. As shown in Figure 4 and Figure 5, there appears to be a trend that as the length of the curb or span increases, there is an increase in the rate of cracking. One longer curb had cracking nearly every foot whereas many curbs less than 30 feet had cracking on average once every 5 feet or greater.

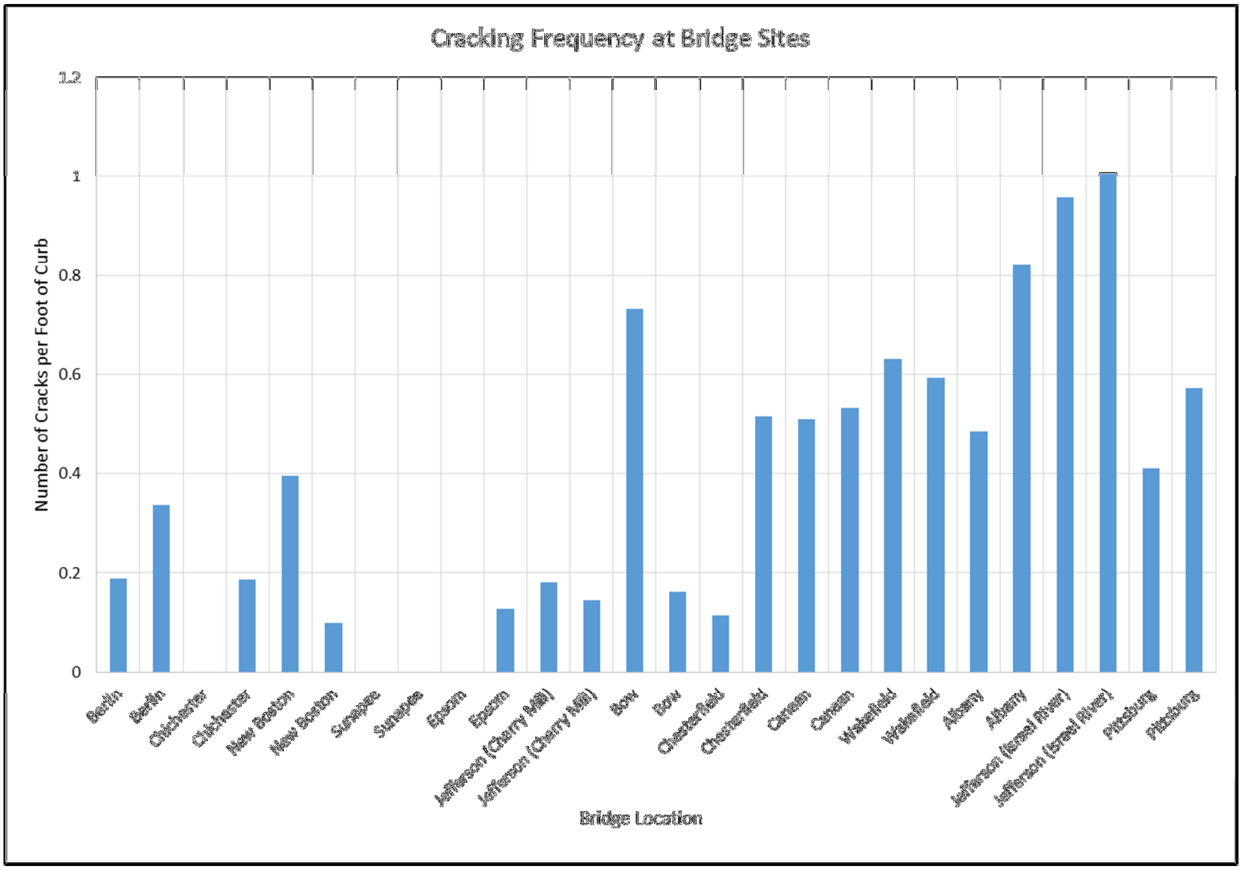

Figure 4: Cracking frequency at visited bridge sites presented by span length from shortest on left to longest on right

The calculated correlation coefficient of the data in **Error! Reference source not found.** is 0.54 which suggests that the rate of cracking has a positive relation to the length of the curb. It is important to note that bridges that are shorter in length tend to be constructed using a concrete superstructure. This changes to a steel beam superstructure as bridges get longer. The use of steel means forces can be carried more efficiently so a small cross section is required than that of a concrete superstructure. This results in a smaller moment of inertia used which means the bridge may exhibit more flexure due to passing traffic. The traffic rushing over the structure may induce a stress wave through the bridge which may place tensile forces on the curb leading to cracking, particularly during the early days after placement.

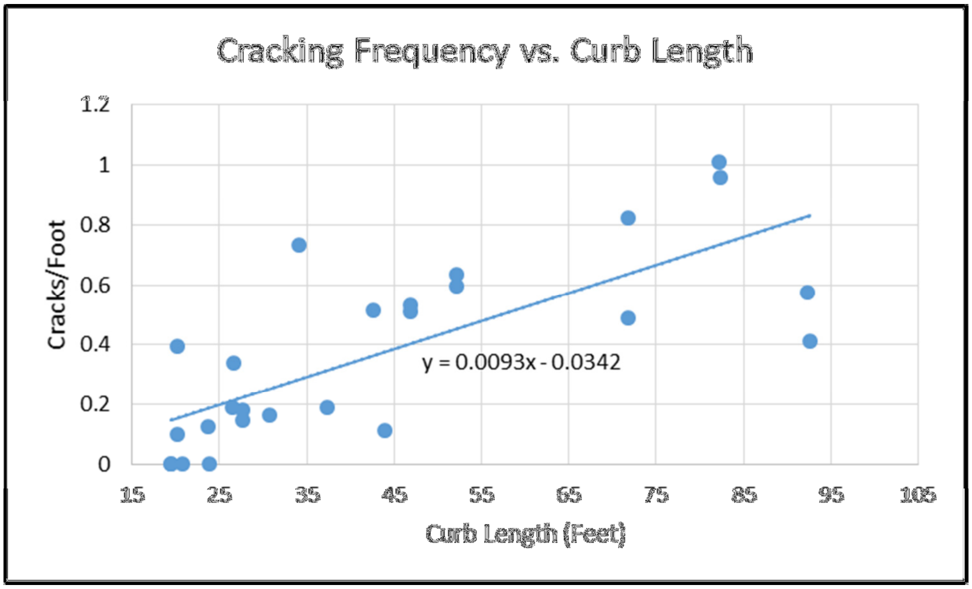

Figure 5: Number of cracks per foot compared to length of curb

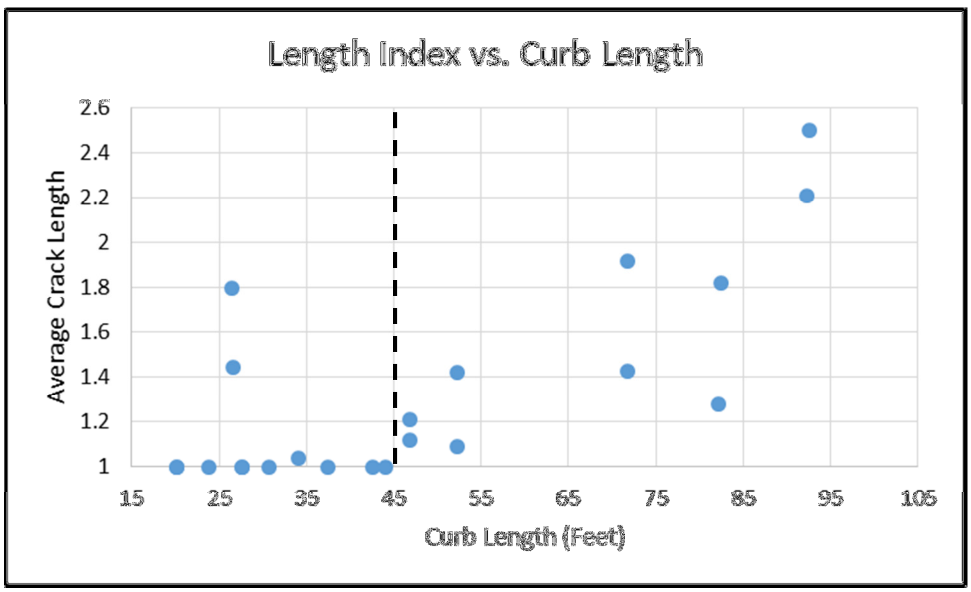

Figure 6: Average crack length compared to curb length

As the curb length increases there is also an increase in the average crack length as measured by the length index. This increase also does not appear to happen until curb lengths of 45 feet are exceeded as seen in Figure 6. Average intensity of cracks does not provide enough evidence that it is affected by curb length (Figure 7).

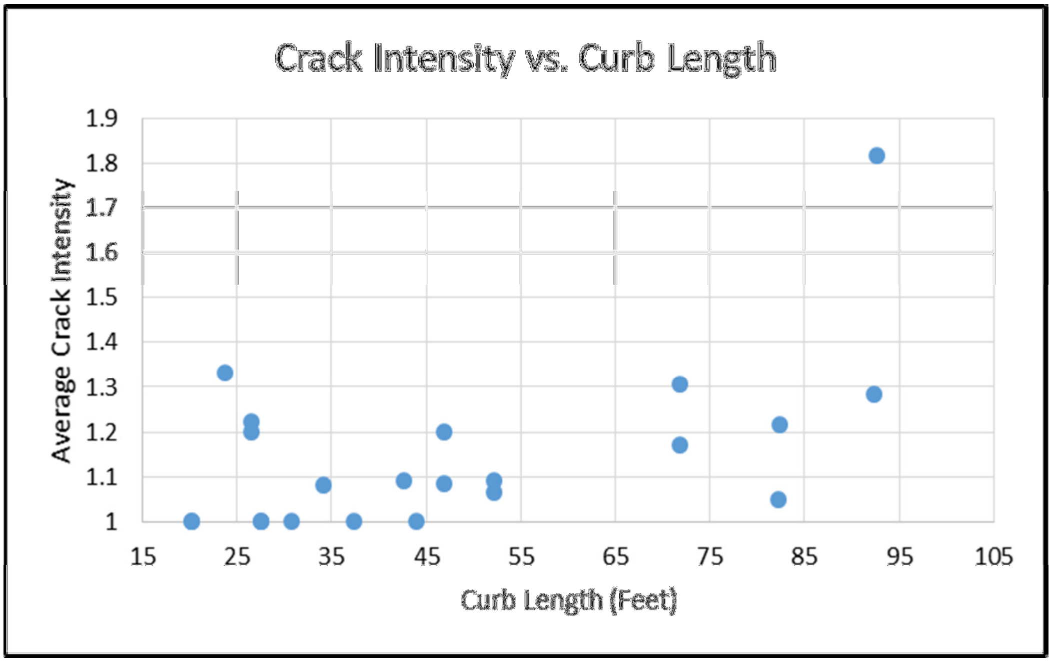

Figure 7: Average crack intensity compared to curb length

In order to try to identify concrete cracks due to shrinkage, the number of cracks per foot per year was plotted as shown in Figure 8. This figure represents how the rate of cracking changes over time. For example, if the number of new cracks formed each year was the same a horizontal line would form. However, Figure 8 shows a decreasing trend. This would mean that the largest amount of crack formation occurs in the first few years of placement and that the rate of crack formation slows as the curb ages. This is in line with what is known about shrinkage in concrete as most of the shrinkage occurs within the first year of concrete being placed. Restrained shrinkage of concrete is likely part of the cause for early-age cracking. It should be noted that in order to validate this hypothesis there is need for tracking of cracking amounts on bridge curbs, which is being conducted to some extent through this study.

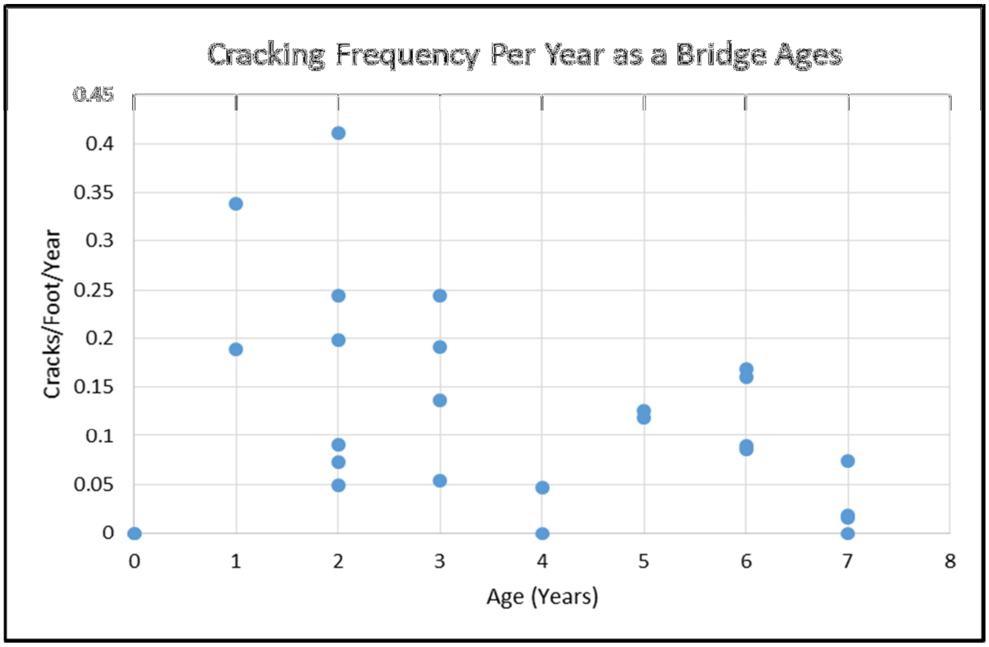

Figure 8: Cracking frequency per year plotted against curb age

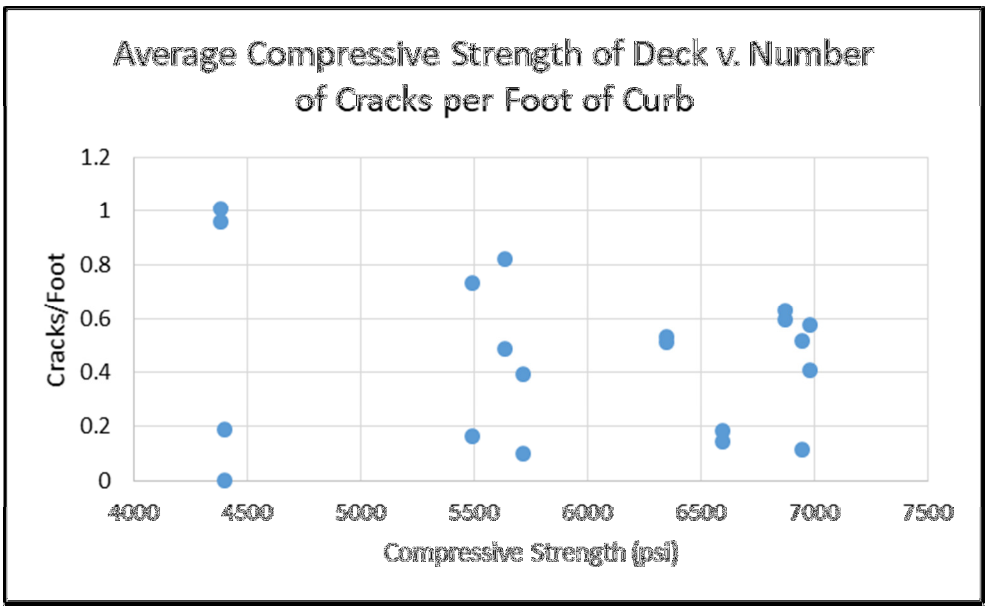

Figure 9: Average deck compressive strength compared to rate of cracking

The compression test data from the bridge decks was averaged and displayed against the cracking rate in Figure 8. It was suggested that a high compressive strength would experience more plastic shrinkage. It would also have a higher modulus of elasticity which may create a more brittle concrete element causing cracking due to traffic induced flexure. The plotted data seems to create a large scatter, particularly at the lower, which makes finding a trend difficult. It should also be noted that the concrete strength is that of the deck and not of the curbing. It is an assumption that the compressive strength of the curb would be similar to the deck.

Concluding Remarks

The set of bridges visited is a representative sample of what other bridges in New Hampshire may be experiencing. One of the strongest cases from the results is that longer bridges may be experiencing more cracking and longer cracks than shorter bridges. Another observation from the data is the hypothesis that most cracking occurs in the first few years after placement. This may indicate that properly controlling cracking early on in the life of a curb will result in much less cracking a decade later.

While the graphs provided show a few of the trends in cracking it does not show all of them. Cracking near guardrail posts was analyzed but the data gathered showed no higher or lower cracking near guardrail posts as compared with the rest of the curb. The rate of cracking in the middle third of the bridge also did not appear to have a high or lower rate of occurrence. The bridge in Pittsburg had curbs that experienced higher intensity in the middle third of the bridge but not a higher rate of cracking. The bridge in Pittsburg was also the longest bridge investigated.

After visiting the existing bridge sites this summer it was determined that a slight procedural change would benefit future crack classification. The change was increasing the intensity rating of 2 from starting at 0.004 inches wide and increasing it to 0.007 inches wide. This reflects recommendations from ACI 224R Table 4.1 as to what crack sizes are reasonable.

It is recommended that on future tests curbs longer periods of curing are used to encourage hydration and a stronger cement matrix. Also, testing a concrete with a compressive strength not greater than 4000 psi may be beneficial as it may reduce the brittleness of the concrete curb. Reducing or restricting traffic may also prove beneficial in reducing early-age cracking as it may prevent microcracks from forming due to traffic vibrations.

Appendix: Field Data

Bridge Cracking Data 1									
Bridge	Town	Side	Structure	Cast	Bridge Length (ft)	Curb Length	Guardrail Locations (Feet from Measured End)	Number of Posts	Length of curb within 1' of posts
045/131	New Boston	North	Concrete	2015	17	20.2	0.9, 7, 13.2, 19.2	4	0.396
045/131	New Boston	South	Concrete	2015	17	20.2	1.0, 7.0, 13.25, 19.25	4	0.396
080/120	Chesterfield	West	Steel	2010	41	44	3.25, 9.5, 15.7, 22.0, 28.25, 34.5, 40.8	7	0.318
080/120	Chesterfield	East	Steel	2010	41	42.6	2.75, 8.9, 15.1, 21.4, 27.6, 33.9, 40.1	7	0.329
052/140	Bow	North	Steel	2014	31	34.1	1.5, 7.7, 14, 20.25, 26.5, 32.75	6	0.352
052/140	Bow	South	Steel	2014	31	30.75	3.1, 9.25, 15.5, 21.75, 28.0, 30.75	6	0.390
130/100	Chichester	West	Concrete	2013	15	20.75	0.9, 7.2, 13.4, 19.75	4	0.386
130/100	Chichester	East	Concrete	2013	15	37.4	2.0, 9.25, 15.6, 21.8, 28.2, 35.3	6	0.321
160/111	Epsom	West	Concrete	2010	21	23.9	1.4, 8.7, 15.9, 23.2	4	0.335
160/111	Epsom	East	Concrete	2010	21	23.75	0.5, 7.8, 15.0, 22.25	4	0.337
230/057	Wakefield	West	Steel	2012	52	52.2	2.1, 10.1, 18.1, 26.1, 34.1, 42.1, 50.0	7	0.268
230/057	Wakefield	East	Steel	2012	52	52.2	2.1, 10.1, 18.1, 26.1, 34.1, 42.1, 50.1	7	0.268
080/148	Albany	South	Steel	2015	73	71.8	1.0, 7.2, 13.4, 19.7, 25.9, 32.2, 38.5, 44.7, 50.9, 57.2, 63.4, 69.7	12	0.334
080/148	Albany	North	Steel	2015	73	71.8	0.9, 7.2, 13.4, 19.7, 25.9, 32.25, 38.4, 44.7, 50.9, 57.2, 63.4, 69.75	12	0.334
112/074	Sunapee	East	Concrete	2017	20	19.5	-	-	-
112/074	Sunapee	West	Concrete	2017	20	19.5	-	-	-
178/141	Canaan	East	Steel	2011	47	46.9	1.0, 8.5, 16.0, 23.6, 31.1, 38.6, 46.0	7	0.299
178/141	Canaan	West	Steel	2011	47	46.9	1.0, 8.3, 15.7, 23.1, 30.5, 37.9, 45.4	7	0.299
089/090	Jefferson (Cherry Mill)	North	Concrete	2015	28	27.6	1.3, 9.7, 18.0, 26.3	4	0.290
089/090	Jefferson (Cherry Mill)	South	Concrete	2015	28	27.6	1.4, 9.7, 18.0, 26.4	4	0.290
087/096	Jefferson (Israel River)	East	Steel	2011	84	82.4	81.2, 73.1, 65.1, 57.2, 49.1, 41.1, 33.1, 25.1, 17.1, 9.1, 1.1	11	0.267
087/096	Jefferson (Israel River)	West	Steel	2011	84	82.2	1.0, 9.0, 17.0, 25.0, 33.0, 41.0, 49.0, 57.0, 65.0, 73.0, 81.0	11	0.268
070/032	Pittsburg	South	Steel	2014	94	92.6	1.4, 9.9, 17.4, 24.9, 32.3, 38.8, 47.2, 55.6, 62.0, 69.5, 76.9, 84.3, 91.7	13	0.281
070/032	Pittsburg	North	Steel	2014	94	92.3	2.1, 9.4, 16.8, 24.3, 31.6, 39.1, 46.5, 53.9, 61.3, 68.7, 76.2, 83.6, 91.0	13	0.282
194/097	Berlin	South	Concrete	2016	12	26.5	0.7, 7.0, 13.3, 19.5, 25.7	5	0.377
194/097	Berlin	North	Concrete	2016	12	26.6	0.8, 7.0, 13.3, 19.5, 25.8	5	0.376

Bridge Cracking Data 2								
Bridge	Town	Side	# of Cracks	# of cracks/foot	# of cracks within 1' of post	Rate of Cracking within 1' of posts	# Cracks in Middle Third of Curb	Cracking Rate in Middle Third of Curb
045/131	New Boston	North	8	0.40	3	0.38	6	0.75
045/131	New Boston	South	2	0.10	0	0.00	0	0.00
080/120	Chesterfield	West	5	0.11	3	0.60	2	0.40
080/120	Chesterfield	East	22	0.52	10	0.45	10	0.45
052/140	Bow	North	25	0.73	10	0.40	10	0.40
052/140	Bow	South	5	0.16	1	0.20	3	0.60
130/100	Chichester	West	-	-	-	-	-	-
130/100	Chichester	East	7	0.19	1	0.14	2	0.29
160/111	Epsom	West	0	0.00	0	-	0	-
160/111	Epsom	East	3	0.13	0	0.00	0	0.00
230/057	Wakefield	West	33	0.63	9	0.27	13	0.39
230/057	Wakefield	East	31	0.59	12	0.39	12	0.39
080/148	Albany	South	35	0.49	11	0.31	12	0.34
080/148	Albany	North	59	0.82	20	0.34	20	0.34
112/074	Sunapee	East	0	0.00	-	-	-	-
112/074	Sunapee	West	0	0.00	-	-	-	-
178/141	Canaan	East	24	0.51	7	0.29	9	0.38
178/141	Canaan	West	25	0.53	6	0.24	11	0.44
089/090	Jefferson (Cherry Mill)	North	5	0.18	3	0.60	0	0.00
089/090	Jefferson (Cherry Mill)	South	4	0.14	2	0.50	2	0.50
087/096	Jefferson (Israel River)	East	79	0.96	24	0.30	27	0.34
087/096	Jefferson (Israel River)	West	83	1.01	20	0.24	28	0.34
070/032	Pittsburg	South	38	0.41	12	0.32	13	0.34
070/032	Pittsburg	North	53	0.57	17	0.32	15	0.28
194/097	Berlin	South	5	0.19	2	0.40	2	0.40
194/097	Berlin	North	9	0.34	4	0.44	4	0.44

Bridge Cracking Data 3									
Bridge	**Town**	**Side**	**Average Crack Intensity**	**Average Crack Length**	**Average Intensity Near Post**	**Average Length Near Post**	**Average Intensity Middle Third**	**Average Length Middle Third**	**Average # of Cracks Per Foot Per Year**
045/131	New Boston	North	1.0	1.0	1.0	1.0	1.0	1.0	0.20
045/131	New Boston	South	1.0	1.0	1.0	1.0	-	-	0.05
080/120	Chesterfield	West	1.0	1.0	1.0	1.0	1.0	1.0	0.02
080/120	Chesterfield	East	1.1	1.0	1.0	1.0	1.1	1.0	0.07
052/140	Bow	North	1.1	1.0	1.0	1.0	1.1	1.0	0.24
052/140	Bow	South	1.0	1.0	1.0	1.0	1.0	1.0	0.05
130/100	Chichester	West	-	-	-	-	-	-	-
130/100	Chichester	East	1.0	1.0	1.0	1.0	1.0	1.0	0.05
160/111	Epsom	West	-	-	-	-	-	-	0.00
160/111	Epsom	East	1.3	1.0	-	-	-	-	0.02
230/057	Wakefield	West	1.1	1.1	1.1	1.0	1.0	1.2	0.13
230/057	Wakefield	East	1.1	1.4	1.0	1.5	1.1	1.6	0.12
080/148	Albany	South	1.2	1.9	1.1	1.9	1.1	2.3	0.24
080/148	Albany	North	1.3	1.4	1.4	1.6	1.4	1.6	0.41
112/074	Sunapee	East	-	-	-	-	-	-	-
112/074	Sunapee	West	-	-	-	-	-	-	-
178/141	Canaan	East	1.1	1.2	1.1	1.6	1.1	1.1	0.09
178/141	Canaan	West	1.2	1.1	1.7	1.2	1.3	1.2	0.09
089/090	Jefferson (Cherry Mill)	North	1.0	1.0	1.0	1.0	-	-	0.09
089/090	Jefferson (Cherry Mill)	South	1.0	1.0	1.0	1.0	1.0	1.0	0.07
087/096	Jefferson (Israel River)	East	1.2	1.8	1.4	2.0	1.3	2.0	0.16
087/096	Jefferson (Israel River)	West	1.0	1.3	1.2	1.6	1.0	1.4	0.17
070/032	Pittsburg	South	1.8	2.5	1.9	2.6	2.1	2.6	0.14
070/032	Pittsburg	North	1.3	2.2	1.3	2.2	2.3	1.6	0.19
194/097	Berlin	South	1.2	1.8	1.5	3.0	1.0	1.0	0.19
194/097	Berlin	North	1.2	1.4	1.5	2.0	1.0	1.0	0.34

Bridge Cracking Notes			
Bridge	**Town**	**Side**	**Notes**
045/131	New Boston	North	Cracks are minor and only extend a few inches transversely
045/131	New Boston	South	cracks only stretch a few inches and are minor
080/120	Chesterfield	West	surface map cracking, two dump trucks drove by at sow speed and had a smaller" bounce than a smaller transit-style van which drove by at a higher speed. Cracks are low in intensity and only extend a few inches along face
080/120	Chesterfield	East	Surface map cracking. Map cracking is more sever on south end of curb then north end. Cracks are low intensity and only extend a few inches
052/140	Bow	North	Map cracking on surface. Low intensity shallow cracking extending only a few inches transversely
052/140	Bow	South	One corner of curb has popped out. Looks like a shear failure. Cracks are small ad lonely extend a few inches
130/100	Chichester	West	Map cracking extends from surface and makes counting actual cracks difficult as transverse cracking and map cracking can not be differentiated.
130/100	Chichester	East	Construction joint located 11.6' in. only minor cracking that does not extend more then a few inches.
160/111	Epsom	West	Fiber reinforced deck, scaling/spalling in the surface
160/111	Epsom	East	More scaling than other side. Cracks only extend a few inches
230/057	Wakefield	West	Very repetitive cracking. Large amounts of Popouts and Scaling
230/057	Wakefield	East	No popouts or scaling unlike previous curb. No cracking over last 8 feet of curb
080/148	Albany	South	Large amount of cracking. Leaning towards multi mechanistic
080/148	Albany	North	Large amount of cracking. Leaning towards multi mechanistic (Shrinkage+Flexure)
112/074	Sunapee	East	No Cracking. Precast curb. Placed in winter of 2017
112/074	Sunapee	West	No Cracking. Precast curb. Placed in winter of 2017
178/141	Canaan	East	A lot of popouts and popouts with rust color around them. Rust color around mortar added to holes where formwork was placed
178/141	Canaan	West	Fewer popouts then neighboring curb but still a couple. Also has rust color around some popouts and formwork remains
089/090	Jefferson (Cherry Mill)	North	Cracks seem to propogate from corner. Coping in good shape
089/090	Jefferson (Cherry Mill)	South	Large amounts of cracking on one wingwall. 3 full length cracks with efflouresence and discontiuity at cold joint
087/096	Jefferson (Israel River)	East	Really in rough shape - scaling and delamination or curb and deck. Cracks seem to start on top panel. This looks like something went wrong during construction.
087/096	Jefferson (Israel River)	West	Looks in rough shape. More cracks than other side but less intensity. Delamination and Scaling.
070/032	Pittsburg	South	Largest cracks measured on existing bridges, longest bridge of existings, more traffic and bridge flexre then winter visit. Road slopes to south end of bridge and has a horizontal curve which has a larger curve to the north.
070/032	Pittsburg	North	
194/097	Berlin	South	Decent amount of cracking for such a small bridge
194/097	Berlin	North	Decent amount of cracking for such a small bridge